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TECHNICAL MEMORANDUM

EPA Region 4, Superfund Division
Barite Hills/Nevada Goldfields Site

B&V Project: 049038
B&V DCN: 49038-0110-06-A-02616R0
EPA Task Order: 038-RICO-A4NZ

Date : August 22, 2017

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Subject: Draft Screening of Technologies for Operable Unit 1 Barite Hills/Nevada Hills Goldfields Site Feasibility Study

This memorandum is a follow up to the teleconference of May 12, 2017 discussing Feasibility Study (FS) scoping issues and potential technologies that could be used for Operable Unit 1 (OU1) of the subject site. This memorandum includes items that were discussed in the teleconference and serves to facilitate further discussion and input regarding the scope and direction of remedial alternatives for OU1.

Since contaminated pit lake water and OU1 groundwater migrates to the North Tributary (OU3) via fractures and seeps and over the spillway, the top priority is to develop remedial alternatives that will prevent or control contaminant migration to OU3. It is expected that the selected remedy for OU1 will reduce the toxicity, mobility and volume of contaminants in OU3 and that after source controls in OU1 have been implemented, water and sediment quality in OU3 will subsequently improve. This phased approach provides the means to monitor the seeps and tributary following actions in OU1.

If monitoring results indicate that residual contaminant inputs remain in OU3, then this adaptive management approach would allow for more cost-effective and design-specific alternatives to be developed to treat or control any remaining threats to human health and the environment in OU3. In addition, the five year review requirement under CERCLA §121 will be used to evaluate the implementation and performance of the phased remedy to determine if it is or will be protective of human health and the environment.

Consequently, development of technologies and alternatives for OU3 is deferred to a second phase that will be based on monitoring results in the North Tributary.

The technology and process screening approach described herein is consistent with the EPA Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA (EPA 1988). Figure 1 from the guidance provides a general flow chart for development of alternatives and shows where this memorandum fits into the process.

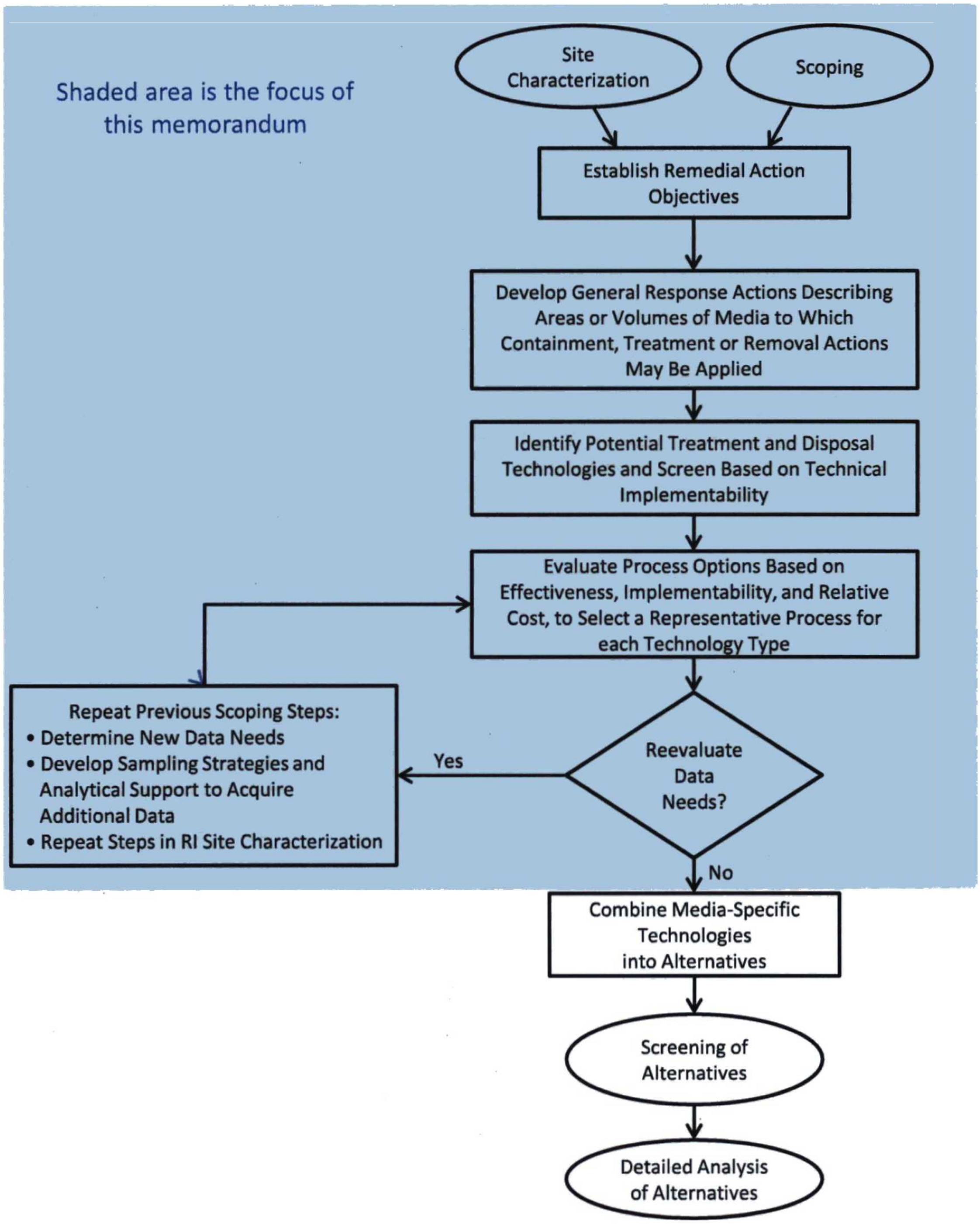

Figure 1. Alternative Development

Remedial Action Objectives (RAOs)

One of the first steps in the FS process is to establish RAOs that provide general descriptions of what the cleanup is expected to accomplish. The draft RAOs that apply to both OU1 and OU3 are used to guide the development of remedial alternatives are listed below. The general remedial strategy is driven by the need to restore and protect the designated uses for the North Tributary.

Surface Water and Sediment

- ***RAO 1:*** Prevent ingestion of, or direct contact with surface water and sediment containing constituents at concentrations which could result in adverse health effects to human and ecological receptors.
- ***RAO 2:*** Prevent or control the migration of contaminated pit lake water to the North Tributary.

Groundwater

- ***RAO 3:*** Prevent ingestion, dermal contact, and/or inhalation of groundwater containing constituents at concentrations which could result in adverse health effects to humans.
- ***RAO 4:*** Prevent or control the migration of contaminated groundwater from the waste dumps to the pit lake and to seeps that discharge to the North Tributary.

Soil/Waste Rock

- ***RAO 5:*** Prevent ingestion, inhalation, or direct contact of soil containing constituents at concentrations which could result in adverse health effects to human and ecological receptors.
- ***RAO 6:*** Prevent or control migration of contaminants in soil or waste rock to groundwater and surface water.

General Response Actions (GRAs)

Remedial technologies evaluated for possible application to OU1 are organized under GRAs which are broad categories of conceptual remediation technical processes or administrative methods to address contaminated media and attain the RAOs. The following GRAs were identified for OU1:

- No action serves as a basis for comparison to other effective and implementable technologies (NCP 1994).
- Institutional controls include instruments such as administrative and legal controls, to minimize the potential for exposure and to ensure the long-term integrity of the remedy.
- Containment technologies such as capping or encapsulation.
- Excavation and disposal of contaminated material.
- *In situ* treatment such as biochemical reactors and constructed wetlands.
- *Ex situ* treatment such as pump and treatment of groundwater.
- Monitored natural recovery (MNR) that documents the effectiveness of natural physical, chemical, or biological processes in reducing contaminant concentrations in sediment to achieve RAOs.

Identification and Screening of Remedial Technologies and Process Options

Several remedial technology process options (RTPOs) have been identified for each applicable GRA for the Site. Remedial technologies refer to general categories of technology types while process options refer to specific processes within each technology type. For example, a vertical containment wall is a process option within the remedial technology of barriers walls under the GRA of containment. The technologies identified are typical of those used in the screening process for former mine operations with acidic mining influenced water.

This step in the FS process identifies a range of RTPOs based on the Remedial Investigation (RI), a review of the literature (e.g., EPA's 2014 *Reference Guide to Treatment Technologies for Mining-Influenced Water*), performance data, and experience in developing other mining-related Feasibility Studies under CERCLA. As presented in Figure 1, this initial screening of remedial alternatives evaluates the GRAs against the following NCP Criteria: effectiveness, implementability, and cost.

Effectiveness is evaluated based on the relative ability of the technology or process option to meet the RAOs in a reasonable timeframe, ensure long-term human health and environmental protection, protect against short-term human and environmental effects during construction, and proven reliability at other sites with chemicals and conditions similar to those in OU1 of the site.

Implementability encompasses both the technical and administrative feasibility of implementing a technology or process option. Technical feasibility refers to the ability to construct, operate, maintain, and monitor the action during and after construction and meet technology-specific regulations during construction. Technical feasibility also applies to the availability of necessary equipment, personnel, and services for implementation or construction, and industry experience in implementing the remedy. Administrative feasibility refers to the ability to obtain approvals to construct the remedy (on-site response actions defined under CERCLA are exempt from the procedural requirements of federal, state, and local environmental laws, though the action must nevertheless comply with the substantive requirements of such laws).

Costs are used to compare different technologies or alternatives. While the total cost of a given technology is not normally estimated during the initial screening described here, relative costs of technologies (i.e., whether they are low, moderate, or high) are evaluated and compared during this initial screening phase. These relative costs are based on professional judgment.

Technologies and process options that: 1) have clearly not been demonstrated as effective in addressing similar conditions at other mining sites; 2) cannot be implemented due to site-specific conditions; or 3) do not meet the RAOs are eliminated from further consideration. The exception is the No Action alternative, which is retained per the NCP in Title 40 Code of Federal Regulations Part 300 to serve as a basis for comparison to other effective and implementable technologies.

Table 1 compares and screens the technologies and process options considered for OU1, including those that were rejected for further consideration. Those options that are retained are further described below.

Description of Retained Remedial Technology Process Options

Institutional Controls

Access and use restrictions such as deed covenants, signs and fencing. For human exposure, potential future consumption of contaminated groundwater poses the greatest threat. Deed covenants to restrict future residential or industrial use could be used to limit exposures.

These controls have no effect on ecological resources or aquatic life in the North Tributary. The site currently is fenced with no trespassing warning signs.

Advantages

- Land use and deed restrictions along with fencing and signs warn of contamination threats.
- Easily implemented.
- Low cost.

Disadvantages

- Serves as a deterrent to exposure not actual protection.
- Leaves contamination in place.
- No protection for aquatic resources.
- Fencing and signage require periodic inspection to ensure they remain intact.

Subaqueous Caps and Covers

In 2008, an estimated 50,000 cubic yards of waste rock were pushed into the pit. The intent was to use pit lake water as an aqueous cover to reduce contact of atmospheric oxygen with sulfide-bearing waste rock. The waste rock rubble in the shallower depths (< 25 ft) in the southern portion of the pit appears to be a major source of acid generation largely due to exposure to relatively high levels of ferric iron, dissolved oxygen and groundwater flow through the waste rock.

Subaqueous caps and covers are containment process options that could be applied to the pit lake. Installing an impermeable cap across the pit lake floor could prevent water in the pit lake from contacting sulfide-bearing waste rock backfill beneath the surface water. The lake floor in this area of the pit (approximately 1.5 acres) has a relatively gradual slope that would be conducive to adding slurry consisting of a neutralizing agent, grouting admixture and residual buffering agent (e.g., lime). Material such as AquaBlok® could also be considered. Low-cost available compounds such as sodium lauryl sulfate (to destroy pyrite oxidizing bacteria), and waste milk and/or whey (to promote biofilm coating preventing acid re-generation) may be used for the partial encapsulation. This technology can be used in conjunction with others to minimize contaminant releases from this source. A treatability study would be needed to determine if the neutralization amendments would be effective in coating the saturated waste rock.

Data Needs

- Saturated waste rock amendment screening treatability studies for proof-of-principle tests for the amendments listed above. If successful then,
- Delineate area of application to determine approximate volumes of amendments, and application methods.

Advantages

- Innovative technology - Should treatability tests show promise then acid generation from the saturated waste rock could be

Disadvantages

- Technology uncommon at other mine sites.
- Requires treatability studies of approximately

substantially reduced.

6 months to determine potential effectiveness.

- Number and sizing of treatments is unknown (e.g., amendment quantities and application rates).

Groundwater Diversion

Based on the geophysical studies conducted by GEL Geophysics, U.S. Geological Survey, and Willowstick®, groundwater migrates from the lower pit lake through fracture zones around the pit to OU3 and a pathway exists for groundwater migration from up-gradient areas through the capped waste rock (CWR) piles to the pit lake. Inflow of highly contaminated groundwater from the CWR to the pit is of most concern in the re-acidification of the pit lake. Diverting groundwater is a form of containment and may be possible by installing a grout curtain or similar feature in the primary flow path from the southwest CWR.

Data Needs

- Current geophysical information suggests that the targeted flow path to the CWR is approximately 300 feet (ft) wide and up to 200 ft deep. A minimum of 3 borehole locations ranging from 140 ft to 200 ft is recommended to delineate groundwater flow paths into and beneath the CWR area.
- Develop a method to determine the flow of groundwater through the CWR and into the pit lake.
- Perform additional geophysical surveys to fine-tune groundwater flow paths based on Willowstick's® investigation on west side of pit.

Advantages

- Would reduce infiltration of groundwater through the CWR thereby reducing contaminated groundwater inflow to the pit.
- Technical resources are available to design and implement grout curtain or similar technology.
- Low long-term operation and maintenance (O&M) costs.

Disadvantages

- May not be able to divert significant groundwater volumes away from the CWR (e.g., if grout curtain cannot be adequately sized).
- If fractured rock is extensive, then this may limit level of implementability.

Hydraulic Containment

Hydraulic containment could be used to withdraw groundwater to prevent discharge to the pit lake or to contain or prevent down-gradient migration of groundwater through the waste rock. Groundwater withdrawal could be accomplished either by extracting shallow groundwater from wells installed upgradient of the waste rock in the southwest slope. The extracted groundwater would require management or treatment prior to discharge to the environment. This could be used with other containment barriers, in the form of clay-cored dams, grout or slurry walls, and similar features could be used to intercept shallow groundwater and force it to a collection area for treatment.

Data Needs

- Determine groundwater depths, flow rates, volumes and water quality.
- Determine depths of waste rock.

Advantages

- Would prevent or reduce groundwater movement through the CWR thereby reducing acid and metals inflow to the pit.
- Technical resources are available to design and implement extraction wells.

Disadvantages

- Would require construction of an active or passive treatment system for the extracted water.
- May have high long-term O&M costs.

Subaerial Caps and Covers

Subaerial caps and covers are containment technologies that are applicable to the waste rock dump area. Process options include compacted clay or soil covers; HDPE, geotextile or other synthetic liners; asphalt or concrete covers; and vegetated soil. This application would involve expanding and enhancing the existing cap across the waste rock dump to further decrease infiltration of precipitation and oxygen through the waste rock dump in order to further limit sulfide oxidation and decrease impacts to groundwater. Although much of the waste rock dump area has been capped, an expansion and/or enhancement of the cap (e.g., completing the HDPE liner to decrease infiltration across the entire cap, rather than just a soil cap). In addition, the existing cap surrounding monitoring wells BH28 and BH29 (approximately 1 acre) is being compromised by shrub and tree growth. Repairs and/or enhancement to this cap to minimize infiltration would be beneficial.

Data Needs

- Delineate area and topography for possible cap expansion.

Advantages

- Relatively small area (< 2 acres) and low cost to reduce infiltration
- Technical resources are readily available for design and implementation various cap designs.
- Low long-term operation and maintenance (O&M) costs.

Disadvantages

- On its own merit, it would not significantly alter acid generation in waste rock beneath the cap.

In Situ Passive Treatment of Surface Water

In situ passive treatment of surface water is a treatment process option for surface water in the pit lake. This process option would involve the addition of lime or caustic to neutralize acidity and soluble organic compounds to spur microbial activity to reduce sulfate and precipitate metals combine with the addition of long-term carbon sources to the upper water column to sustain microbial life. The seasonal and temporal changes in pit lake chemistry in relation to the various neutralization events are documented in the RI. One of the major factors affecting the success of raising the lake pH is the rapid re-acidification that appears to occur in response to groundwater inflow through the CWR. In addition, it appears that microbial activity in the water column is diminished in part due to depleted soluble carbon in the upper water column. Developing a means to provide both short-term carbon (e.g., methanol, molasses) and long-term carbon (e.g., large carbon "tea bags" with wood chips) may help to alleviate this issue and raise alkalinity that is necessary to sustain a pH >6 and maintain reducing conditions through much of the water column. Other contributing factors to re-acidification include, but not limited to, the increase in redox conditions and dissolved oxygen levels in the lower water column.

Since 2014, new lake bathymetry data was used to estimate 73 Mg of water, which is higher than used previously (~ 60 Mg). Water volume estimates may have affected previous amendment successes. This technology should be used in combination with other technologies that reduce acid inputs to the lake.

Data Needs

- Review and refine the current estimate of water volume in the lake as new data are generated to increase accuracy.
- Monitor pit lake water quality quarterly at the surface, and above and below the chemocline as consistent monitoring will provide better estimates of potential amendment options.

Advantages

- Likely to raise pH above 6 and reduce metals concentrations, thereby reducing threat to the North Tributary from discharge of contaminated water over the pit spillway.
- Technical capability and cost assumptions to deliver various amendments has been demonstrated.

Disadvantages

- May require more than one amendment event, thus long-term monitoring and higher O&M costs are expected.

Amendments to Waste Rock

Amendments to waste rock could be used as an *in situ* treatment process option and as a containment/source control strategy for solids in the waste rock dumps. This RTPO could be implemented in a manner that reduces future acid generation from sulfide minerals in the dumps. Given that the CWR appears to be a major source of contamination to the pit lake, various amendments could be delivered into the CWR to reduce acid generation and metals mobility. This technology can be used in conjunction with others such as partial removal of the CWR to minimize contaminant releases from this source. Sovereign Consulting has proposed adding low-cost available such as sodium lauryl sulfate (to destroy pyrite oxidizing bacteria), waste milk and whey (to promote biofilm coating of sulfide minerals to prevent acid re-generation). Since the waste rock is covered by about 2 to 3 feet of compacted soil and a well-vegetated cover (and partly capped with a geomembrane liner), methods to deliver the amendments into the CWR will need to be evaluated. Potential delivery methods include surface application of amendments that infiltrate through the cap or injection through vertical or horizontal tubes inserted via directional drilling underneath the cap.

Data Needs

- Waste rock amendment screening treatability studies for proof-of-principle tests for the amendments listed above. If successful then,
- Conduct similar tests with waste rock saturated with groundwater obtained from the CWR wells (i.e., BH26 - BH29) to determine the effect of local groundwater on the amendments.
- Identify effective means of delivery to the CWR.

Advantages

- Innovative technology - Should treatability tests show promise then acid generation from the CWR could be substantially reduced on a long-term or semi-permanent basis.

Disadvantages

- Technology uncommon at other mine sites.
- Requires treatability studies of approximately 6 months to determine potential effectiveness.
- Number and sizing of treatments is unknown (e.g., amendment quantities and application

rates); may require some O&M costs.

- Distribution of amendments would be difficult to control.

Amendments to Groundwater

Adding amendments to groundwater is an *in situ* treatment process option for groundwater within and up-gradient of the waste rock dumps. This strategy also could be applied to groundwater discharging from the pit lake. Current data suggest that as groundwater migrates through the CWR it becomes acidified and dissolves metals released from the waste rock by sulfide oxidation. The addition of alkalinity (NaOH or similar compounds) into the CWR directly or into the groundwater flowing through the CWR should reduce acid generation. Carbon such as methanol could also be injected to spur microbial activity. Would require a network of injection wells to send compounds to the correct depth and radius. This RPTO Would likely be used in conjunction with the groundwater diversion approach to minimize treatment of large volumes of groundwater.

Data Needs

- Install additional borings through the CWR and hydraulic testing of wells in several locations to understand lateral and vertical variability of transmissivity.
- Based on hydrogeologic and water quality data from new and existing wells, determine the quantities of neutralizing reactants needed to raise pH >5.
- Identify effective means to deliver amendments into the CWR such as via vertical and/or horizontal injection wells.

Advantages

- Acid generation from the CWR may be substantially reduced.
- Effectiveness of adding neutralizing compounds to acidic media is well documented.
- Technical capability to deliver amendments has been demonstrated.

Disadvantages

- Would require alkalinity injection system for repeated amendment events, resulting in relatively high capital costs and O&M expenditures.

Partial Excavation of Capped Waste Rock

Partial excavation of waste rock is a removal and source control process option that could be applied to the subaerial waste rock dumps. There is an existing soil cap of approximately 1 acre in the vicinity of monitoring wells BH28 and BH29. Waste rock beneath this cap is a source of acid generation due to the interchange of pit lake water and groundwater input through the waste rubble. This would entail pulling waste rock back from the lake. This may also include pulling some of the waste rock out of the lake (which would require temporarily lowering the lake level). Removing this source and replacing it with clean fill will reduce acid formation and improve water quality of the lake. The excavated material could be disposed of on the Barite Hill site or at an off-site repository. This RTPO could be used with other technologies such as putting a cutoff wall to force groundwater to the surface and treat it in a passive system within the excavated area.

Data Needs

- Soil borings through the existing cap and near shore lake bottom to estimate volume and depths of material to be removed.

Advantages

- Removes a portion of acid generating source material.
- Common, easily implementable technology.

Disadvantages

- Must be used with other process options to control acid generation and improve lake water quality.

On-Site Disposal of Excavated Material

This RTPO for disposal is linked to the excavation technologies. Waste rock, sediment, and other mine wastes can be disposed of in one or more repositories constructed on the Barite Hill site. Depending on the environmental behavior of the solids requiring disposal (e.g., leachability, acid generation potential), a repository may be constructed with or without a liner and wastes may be either contained or isolated. A facility constructed on site would be expected to comply with requirements for Subtitle D landfills. An on-site repository offers a high level of overall T/M/V reduction (albeit with a transference of volume to the repository location), but also has a substantial capital cost and a low level of long-term liability associated with the selected landfill.

Data Needs

- Identify suitable repository areas access routes and potential issues with liner construction and capping of landfill.

Advantages

- Offers a high level of overall toxicity/mobility/ volume reduction (albeit with a transference of volume to another location).
- Common, easily implementable technology.

Disadvantages

- Substantial capital cost and a low level of long-term liability associated with the selected landfill.

Open Limestone Channel (OLC)

Open limestone channels are an *ex situ* passive treatment process option for oxygenated surface water with net acidity but generally low concentrations of iron. OLC technology could be used to treat surface water discharged from the pit lake via the spillway. Flow across the spillway would be diverted into a pipe and conveyed to an OLC which is a lined channel constructed of cobble- or gravel-sized limestone rock. A small settling basin may be required at the outlet of the channel to precipitate aluminum and other metal precipitates that form as pH is increased prior to discharge to the North Tributary. Depending on water quality in the upper pit water column, the length of the open channel and the contact time of water with limestone, water discharged from the system may or may not meet State water quality standards (WQS). The addition of water with residual alkalinity to OU3 could be expected to cause precipitates to form in the North Tributary as the alkalinity reacts with dissolved iron and other metals in the creek. This floc would continue downstream for a considerable (and unknown) distance until it settles out. There would not be any expected performance drop-off following dry periods when the pit lake does not discharge. Periodic monitoring of the channel would be required to ensure that the limestone does not become armored with iron precipitates and lose reactivity. The system could be sized to handle a variety of flows, but appropriate gradients would need to be determined to ensure a required minimum contact time.

Data Needs

- Only one surface water sample has been collected adjacent to the spillway. Need to collect samples adjacent to spillway on a quarterly basis and during one or more storm events to understand water quality and mass loading to the North Tributary.
- Estimate the volume of water discharging over the spillway by continued use of the transducer measuring water elevation in the lake and applying a weir equation (or similar) to calculate water discharge. This would assist in understanding the volumes of water requiring treatment. This may include rainfall-runoff modeling of selected storm events under different antecedent storage conditions in the pit lake to gain a clearer understanding of water discharges from the lake to the North Tributary.
- Estimate system size due to limited area below spillway.

Advantages

- Removal of metals and raising pH of spillway water reduces risk to the North Tributary.
- OLCs are common at mine sites and technical resources to implement are well known.

Disadvantages

- Limited area below spillway may interfere with construction design.
- Will require monitoring of system performance and of the upper North Tributary.

Sulfate-Reducing Bioreactor

Sulfate-reducing bioreactors are an *ex situ* treatment process option for surface water with net acidity and elevated concentrations of metals, sulfate, and other constituents. Flow across the spillway would be diverted into a pipe and conveyed to a passive treatment system to remove metals and raise pH. The system would require some area of relatively flat ground (approximately 0.5 acre) but they could also be installed in modular form in tanks or as permeable reactive barriers to treat other contaminated waters on site. Likely system components would include a surge pond or head tank to meter flow into the bioreactor, an aerobic settling pond or wetland to precipitate metals, remove BOD and add dissolved oxygen, and possibly a manganese rock filter. The system would be expected to create water that meets or is close to meeting WQS. However, the system performance is dependent on flow rates, influent water quality and available land area for construction. Sulfate-reducing bioreactors are a passive treatment option that would not require power or regular maintenance. However, they are not a "walk away" technology and would require periodic monitoring and maintenance of inlets/outlets to ensure system performance and efficiency. Replacement of the substrate and reconstruction of the system would be required every 20 to 30 years.

Data Needs

- Same as for the OLC.

Advantages

- Removal of metals and raising pH of spillway water reduces risk to the North Tributary.
- Bioreactors/wetlands are common technologies at mine sites and technical resources to implement are well known.

Disadvantages

- Continued function of the system would require a nearly continuous flow of water; the system may not perform well if it is permitted to dry out when the pit lake does not discharge.
- Limited area below spillway will likely interfere

with effective construction design.

- Will require more detailed monitoring of system performance and North tributary.

Ex situ Aerobic Wetland Pond

Constructed aerobic wetlands are shallow ponds filled with gravel, organic matter, and soil which are planted with wetland species such as cattails. Water ponds within the cells to depths of 6 to 12 inches and typically flows across the pond (rather than through the substrate). Aerobic wetlands permit oxidation and hydrolysis of iron and other metals at times assisted by plant uptake and microbial activity. The footprint required for an aerobic pond depends on flow rate but is typically rather large to permit sufficient residence time for oxidation and flow velocity that is low enough to allow fine-grained precipitates to settle.

As a primary treatment option, aerobic wetlands are generally inefficient at removing high concentrations of metals and neutralizing acidity; they are not expected to significantly remove manganese or sulfate. However, they are widely used as a polishing step to add oxygen, remove dissolved sulfide and biochemical oxygen demand, and promote iron hydrolysis and precipitation in water discharged from anaerobic bioreactors or wetlands. This RTPO would be used in conjunction with the sulfate reducing bioreactor as a polishing step for treated water.

Data Needs

- Same as for the OLC.

Advantages

- Widely used in this application, relatively inexpensive to construct and require little maintenance.

Disadvantages

- Performance monitoring and periodic cleanout of accumulated sediment and precipitates would be required.
- Function could be interrupted in winter months when temperatures are low enough to cause water in the pond to freeze.

Manganese Rock Filters

Manganese rock filters are a type of passive aerobic treatment. While constructed aerobic wetlands are ineffective at removing manganese due to the high pH (>8) required for Mn^{2+} to be oxidized to insoluble Mn^{4+}, rock filter technology utilizes bacteria or green algae to promote manganese oxidation in the presence of a limestone substrate, allowing manganese oxide to be precipitated onto the limestone fragments. Manganese rock filters are constructed as a bed of limestone gravel (18 to 24 inches thick) that is inoculated with bacteria or algae. Oxygenated manganiferous water that has been treated to remove iron and other metals is passed through the rock filter to remove manganese. Rock filters are seeing increased use at mine sites to remove manganese as the third step in a passive treatment train (anaerobic cell, aerobic cell, rock filter).

Data Needs

- Rock filters are sized to permit sufficient residence time for manganese oxidation and removal as determined through bench- and pilot-scale testing.

- On-site pilot-scale treatability studies are recommended to evaluate seasonal effects

Advantages

- A developed technology that is inexpensive to construct and maintain.
- Inoculants are typically readily obtained from rock filters in use at other mine sites.

Disadvantages

- Over time, manganese deposition within the filter will reduce the permeability of the gravel and require its replacement.
- Performance monitoring is required to ensure that preferential flow paths through the drain do not develop over time, which would reduce residence time and lower efficiency.
- Removal efficiency may vary seasonally with lower efficiency in cold winter months when bacterial metabolism and algal growth slows.

Ex situ Treatment of Pit Lake Water

Drain lake by pumping at least 73 Mgal water through an on-site treatment facility and discharge clean water to North Tributary. An on-site treatment facility will be needed to raise pH and remove metals in order to meet effluent criteria acceptable to the State of South Carolina. Several treatment options such as pH adjustment, ion-exchange, clarification and filtration are available; all would require power to pump water from the lake and operate the treatment plant, reagent storage, a sludge handling and management system, and a discharge line. Assuming an average continuous flow of 100 gpm, treatment of 73 Mgal would require about 1.5 years assuming no additional inflow. A treatment system would need to accommodate large variations in water chemistry, particularly near bottom of water column. Treatment sludge would be temporally stored on site for eventual placement back into the pit.

Exposure of saturated waste rock and bottom sediment to oxygen would release additional acid. Given contaminated groundwater inflow and precipitation over the course of a year, treatment is likely to be greater than 73Mgal.

This technology would need to be used in conjunction with other technologies such as controlling oxidization of bottom sediment, capping and backfilling the pit, and managing contaminated groundwater inflow.

Data Needs

- Treatability studies to identify the most cost-effective treatment method(s).
- Determine location for a suitable outfall.
- Estimate additional inputs from groundwater and rainfall/runoff that would require treatment beyond just the pit lake volume.
- Identify energy sources for the treatment plant.

Advantages

- Removal of lake water may reduce seepage flow through fractures to the North Tributary.
- Water treatment is a common technology at mine sites.

Disadvantages

- Would require laboratory treatability study of variable lake water quality to identify most cost-effective treatment technology.
- Draining lake may not control seepage to

- Treatment would require power and would be expensive.

North Tributary due to contaminated groundwater beneath pit and through the existing waste rock.

- High capital cost and O&M for questionable reduction of risk to the North Tributary.

Constructed Anaerobic Wetlands

Constructed anaerobic wetlands are an *ex situ* treatment process option for treatment of net acidic water with high concentrations of metals and sulfate. Treatment is accomplished through sulfate reduction and precipitation of metals as sulfides and hydroxides under reducing conditions. Constructed anaerobic wetlands use biochemical processes to neutralize acidity and remove metals from acidic mining influenced water. They may be configured for water to flow horizontally or vertically through the substrate. Substrate composition varies but typically includes a mix of organic materials such as woody debris (e.g., chips or sawdust), compost (e.g., mushroom, manure), and other vegetative matter (e.g., hay); a bacteria source (most commonly fresh manure); and a source of alkalinity (e.g., limestone).

Sulfate-reducing bacteria within the substrate convert sulfate in untreated water to hydrogen sulfide, which reacts with dissolved divalent metals such as cadmium, copper, iron, and zinc to precipitate as sulfide minerals within the substrate. Other metals (e.g., aluminum, chromium) are removed as hydroxide phases as pH is raised by the dissolution of limestone and microbial bicarbonate production. Sulfate-reducing bacteria function optimally at pH of 5 or higher. Consequently, the rate at which acidity enters the treatment system is critical to its success; too much acidity will overwhelm microbial bicarbonate production and lead to a decrease in pH that causes sulfate reduction to slow or cease.

Treatment of storm runoff would require additional anaerobic wetland capacity. Maintaining a healthy microbial population capable of treating the additional load imparted by storm flow is critical to the success of any passive anaerobic system that relies on microbial activity to treat water. Consequently, constructed anaerobic wetlands would need to be designed with the capacity to treat storm flow, and then be operated during base flow in a manner that maintains microbial health.

This RTPO could be applied to the pit only in conjunction with elimination of the pit lake water. After the lake is drained, implementation would require other technologies such as excavating the backfilled waste rock in the pit or capping the pit bottom with a liner or other cap (e.g., Aquablok) then an engineered wetland system would be designed on top to capture the residual contaminated groundwater and runoff. (Given the depth of the pit, backfilling and re-shaping the pit would be necessary to manage the predicted hydrology of the wetland; and the spillway would likely be lowered to allow the assumed clean water to be discharged into the North Tributary).

Data Needs

- Would need to develop initial design capacity and sizing to manage rainfall, runoff to the deep pit, and groundwater input to determine feasibility.
- Determine approximate volumes and sources of backfill and other capping material.

Advantages

- Removal of metals and raising pH of spillway water reduces risk to the North Tributary.

Disadvantages

- Would likely require treatability studies of contaminated groundwater inflow volumes

- Engineered wetlands are relatively common technologies at mine sites and technical resources to implement are well known.

and quality to determine wetland size.

- High capital cost and O&M for minimal reduction of risk to the North Tributary.
- Would require detailed monitoring of wetland system performance.

Table 1. Screening of Remedial Technologies for OU1 (page 1 of 3)

General Response Action	Remediation Technology and Process Option	Description of Process Option	Effectiveness	Implementability	Cost	Retained	Screening Comments
No Action	None	No action taken	Not effective	Implementable	No cost	Yes	Required for baseline comparison
Institutional Controls	**Access and Use Restrictions**						
	Deed covenants	Prohibit residential use of site including groundwater as potable water source. Restrict development of area around the pit lake through restrictive language in deeds and other instruments of property transfer.	Effective	Implementable	Low	**Yes**	Not effective to reduce risks to aquatic life in the North tributary. Would be used only in conjunction with other technologies. May apply use restriction to prevent using OU1 groundwater and pit lake as a potable water source.
	Signs	Restrict access to site areas or provide health advisories.	Effective	Implementable	Low	**Yes**	Would be used in conjunction with other technologies. Signs and fencing around the pit area in attempt to deter exposure.
	Fencing	Restrict access to site.	Effective	Implementable	Low	**Yes**	
Monitored Natural Attenuation	Monitor environmental parameters	Monitor surface water and sediment quality.	Will not attain RAOs for Pit Lake.	Implementable	Low	No	Not likely to reduce threat to North tributary due to continual recontamination by groundwater.
Containment	**Subaqueous Caps and Covers**	Cover acid generating waste rock in southern area of pit floor with a pumpable slurry consisting of a neutralization agent, grouting admixture and residual buffering agent (e.g., lime).	Potentially effective - would require treatability studies. May be less effective in highly irregular pit floor.	Implementable	High	**Yes**	Would be used in conjunction with other technologies. Lake sediment not expected to discharge over spillway. No risk reduction anticipated in the lake or in the North Tributary. Most acid inputs appear from groundwater that also flows beneath pit.
	Sediment solidification / stabilization	Addition of material to sediment such as cement kiln dust to stabilize and contain metals in sediment.	Not effective	Would need to drain lake to access specific fractures.	High	No	No additional risk reduction would be achieved.
	Grout fracture zones	Grout major fractures through pit related to seeps.	Not expected to be effective due to highly fractured bedrock.	May be limited depending on slurry wall depths.	High	No	Multiple fractures and seeps identified. Specific pathways unknown and may occur beneath the pit.
	Groundwater diversion	Use grout walls to divert majority of groundwater from flowing through buried waste rock.	Effective provided bedrock is not extensively fractured.	Implementable	Medium	**Yes**	Groundwater flow paths and waste rock areas are reasonably characterized. Can be used with other technologies.
	Hydraulic containment	Draw down groundwater to a level below the waste rock to prevent acidic inflow into the pit lake.	Effective	Implementable	Medium	**Yes**	Somewhat dependent on groundwater recharge rates after pumping in fractured bedrock. Can be used with other containment technologies
	Subaerial caps and covers	Expand and/or enhance cap in southwest portion of waste rock area to reduce infiltration to groundwater.	Effective	Implementable	Low	**Yes**	Would be used with other technologies to reduce area of likely infiltration.

Table 1. Screening of Remedial Technologies for OU1 (continued page 2 of 3)

General Response Action	Remediation Technology and Process Option	Description of Process Option	Effectiveness	Implementability	Cost	Retained	Screening Comments
Containment	Drain lake and backfill	Drain lake by pumping water through an on-site treatment facility and discharge clean water to North Tributary. Backfill entire pit to form a mound with runoff controls.	Potentially effective	Difficult to implement with large volume of water to treat and large amount of backfill material.	High	No	Expensive to treat at least 75 million gallons water. Would need to blast highwalls to assist in backfill but would require large volumes of additional on-site and potentially off-site fill material. May not substantially reduce contaminated groundwater.
In situ Treatment	**Neutralization of pit lake**	Treat lake with alkalinity, organic carbon and other potential amendments.	Temporarily effective. Long-term effectiveness not expected without other controls.	Implementable	Medium	**Yes**	Would only be used in conjunction with other technologies such as groundwater controls. The pit lake has been treated several times (1998, 2008, 2009, 2010, 2012, and 2016). In each case, the median pH of the water degraded to <3.5 due to continued recontamination by poor groundwater quality.
	Amendments to waste rock	Inject chemicals (e.g., sodium lauryl sulfate, waste milk, whey) into waste rock to reduce acid generation.	Potentially effective - would require treatability studies.	May be difficult to amend beneath existing cap and in saturated waste rock zone.	Medium	**Yes**	Effectiveness largely unknown to site-specific waste rock (need treatability study). May be difficult to inject beneath, or infiltrate through, the existing cap over waste rock (another treatability study). Would likely be used in conjunction with other technologies.
	Amendments to groundwater	Install series of alkalinity injection wells in plume flowing through waste rock.	Potentially effective when combined with other technologies.	Implementable	High	**Yes**	May be used in conjunction with groundwater slurry wall and lake neutralization. Would likely require installation of new wells in affected flow paths.
Excavation	**Partial excavation of capped waste rock**	Pull back existing soil cap in selected areas and excavate waste rock using conventional earthmoving equipment. Amend remaining material and backfill.	Partially effective – removes source of acid-generating material.	Implementable	Low	**Yes**	Only removes a small portion of acid generating material but can readily be combined with other technologies.
Disposal	**On-site disposal**	Waste rock would be disposed of and managed (capped) within the former mine site.	Effective	Easy to implement	Low	**Yes**	There is sufficient space to place the expected quantities of material in an area not subject to groundwater infiltration.
	Off-site disposal	Disposal of material at a permitted landfill.	Effective	Implementable	High	No	Acid generating material would likely fail leach test requirements. High costs of transport and management.
Ex situ treatment of pit water discharging to North Tributary via the spillway	**Open limestone channel (OLC)**	Flow across the spillway would be diverted into a pipe and conveyed to an open limestone channel or a similar passive system to raise pH and precipitate metals.	Effective depending on pH, metals concentrations and flow volumes.	Implementable	Medium	**Yes**	Does not require continuous flow from lake. Short-term, large discharges from spillway may reduce effectiveness.
	Anoxic limestone drain (ALD)	Similar to the OLC, water would be piped from the spillway to an anoxic limestone drain.	May be effective depending on pH, oxygen, iron concentrations and flow volumes.	Implementable	Medium	No	Oxygenated pit water would need to be passed through a system to remove oxygen prior to entering the ALD.

Table 1. Screening of Remedial Technologies for OU1 (continued page 3 of 3)

General Response Action	Remediation Technology and Process Option	Description of Process Option	Effectiveness	Implementability	Cost	Retained	Screening Comments
Ex situ treatment of pit water discharging to North Tributary via the spillway	**Sulfate-reducing constructed bioreactor**	Flow across the spillway would be diverted into a pipe and conveyed to a passive treatment system to remove metals and raise pH.	Effective if combined with other technologies.	Implementable	Medium	**Yes**	Continued function of the system would require a nearly continuous flow of water; the system may not perform well if it is permitted to dry out when the pit lake does not discharge. Would need relatively flat area (0.5 - 1 acre).
	Aerobic wetland pond	A "polishing" passive treatment pond to remove dissolved sulfide, add oxygen and promote iron precipitation.	Effective if combined with other passive technologies to treat discharges.	Implementable	Medium	**Yes**	Aeration step required after treatment to remove dissolved sulfide and BOD and add oxygen prior to discharge to surface water.
	Manganese Rock Filters	A "polishing" passive treatment step to remove expected high levels of manganese prior to discharge to the North Tributary.	Effective if combined with other passive technologies to treat discharges.	Implementable	Medium	**Yes**	Considered a third step in passive treatment when manganese is elevated.
EX situ treatment of groundwater	Pump and treat groundwater	Pump contaminated groundwater and send through a treatment system that may include lime additions, zero-valent iron or other reactants.	Potentially effective	Implementable	High	No	Not practical due to large volumes to be treated with on-site active or passive treatment system, and potential disposal of precipitated sludge.
	Constructed anaerobic wetlands	Construct wetland in the pit after water has been drained to treat groundwater inflow and runoff to the pit.	Potentially effective	Requires implementing with series of other technologies	High	**Yes**	This RTPO could be applied to the pit only in conjunction with elimination of the pit lake water and re-configuring the pit floor.
Ex situ treatment of pit lake water	**Drain and treat pit lake water**	Drain lake by pumping water through an on-site treatment facility and discharge clean water to North Tributary. Several treatment options such as pH adjustment, ion-exchange, clarification and filtration.	Potentially effective	Requires implementing with series of other technologies	High	**Yes**	Only if used in conjunction with other technologies such as groundwater containment and encapsulation of exposed bottom sediments to minimize acid generation and mobilization of metals. Unknown how seeps may be affected. Estimated 73 Mgal water to be treated. Precipitated metals from treatment would require clarification and/or filtration. Disposal of treatment sludge also required. Metals potentially could be removed to WQS (would not include manganese). O&M of on-site treatment plant expected to be high. Expensive relative to minimal risk reduction to the North Tributary.

Table 1. Screening of Remedial Technologies for OU1 (page 1 of 3)

General Response Action	Remediation Technology and Process Option	Description of Process Option	Effectiveness	Implementability	Cost	Retained	Screening Comments
No Action	None	No action taken	Not effective	Implementable	No cost	Yes	Required for baseline comparison
Institutional Controls	Access and Use Restrictions Deed covenants	Prohibit residential use of site including groundwater as potable water source. Restrict development of area around the pit lake through restrictive language in deeds and other instruments of property transfer.	Effective	Implementable	Low	**Yes**	Not effective to reduce risks to aquatic life in the North tributary. Would be used only in conjunction with other technologies. May apply use restriction to prevent using OU1 groundwater and pit lake as a potable water source.
	Signs	Restrict access to site areas or provide health advisories.	Effective	Implementable	Low	**Yes**	Would be used in conjunction with other technologies. Signs and fencing around the pit area in attempt to deter exposure.
	Fencing	Restrict access to site.	Effective	Implementable	Low	**Yes**	
Monitored Natural Attenuation	Monitor environmental parameters	Monitor surface water and sediment quality.	Will not attain RAOs for Pit Lake.	Implementable	Low	No	Not likely to reduce threat to North tributary due to continual recontamination by groundwater.
Containment	**Subaqueous Caps and Covers**	Cover acid generating waste rock in southern area of pit floor with a pumpable slurry consisting of a neutralization agent, grouting admixture and residual buffering agent (e.g., lime).	Potentially effective - would require treatability studies. May be less effective in highly irregular pit floor.	Implementable	High	**Yes**	Would be used in conjunction with other technologies. Lake sediment not expected to discharge over spillway. No risk reduction anticipated in the lake or in the North Tributary. Most acid inputs appear from groundwater that also flows beneath pit.
	Sediment solidification / stabilization	Addition of material to sediment such as cement kiln dust to stabilize and contain metals in sediment.	Not effective	Would need to drain lake to access specific fractures.	High	No	No additional risk reduction would be achieved.
	Grout fracture zones	Grout major fractures through pit related to seeps.	Not expected to be effective due to highly fractured bedrock.	May be limited depending on slurry wall depths.	High	No	Multiple fractures and seeps identified. Specific pathways unknown and may occur beneath the pit.
	Groundwater diversion	Use grout walls to divert majority of groundwater from flowing through buried waste rock.	Effective provided bedrock is not extensively fractured.	Implementable	Medium	**Yes**	Groundwater flow paths and waste rock areas are reasonably characterized. Can be used with other technologies.
	Hydraulic containment	Draw down groundwater to a level below the waste rock to prevent acidic inflow into the pit lake.	Effective	Implementable	Medium	**Yes**	Somewhat dependent on groundwater recharge rates after pumping in fractured bedrock. Can be used with other containment technologies
	Subaerial caps and covers	Expand and/or enhance cap in southwest portion of waste rock area to reduce infiltration to groundwater.	Effective	Implementable	Low	**Yes**	Would be used with other technologies to reduce area of likely infiltration.

Table 1. Screening of Remedial Technologies for OU1 (continued page 2 of 3)

General Response Action	Remediation Technology and Process Option	Description of Process Option	Effectiveness	Implementability	Cost	Retained	Screening Comments
Containment	Drain lake and backfill	Drain lake by pumping water through an on-site treatment facility and discharge clean water to North Tributary. Backfill entire pit to form a mound with runoff controls.	Potentially effective	Difficult to implement with large volume of water to treat and large amount of backfill material.	High	No	Expensive to treat at least 75 million gallons water. Would need to blast highwalls to assist in backfill but would require large volumes of additional on-site and potentially off-site fill material. May not substantially reduce contaminated groundwater.
In situ Treatment	**Neutralization of pit lake**	Treat lake with alkalinity, organic carbon and other potential amendments.	Temporarily effective. Long-term effectiveness not expected without other controls.	Implementable	Medium	**Yes**	Would only be used in conjunction with other technologies such as groundwater controls. The pit lake has been treated several times (1998, 2008, 2009, 2010, 2012, and 2016). In each case, the median pH of the water degraded to <3.5 due to continued recontamination by poor groundwater quality.
	Amendments to waste rock	Inject chemicals (e.g., sodium lauryl sulfate, waste milk, whey) into waste rock to reduce acid generation.	Potentially effective - would require treatability studies.	May be difficult to amend beneath existing cap and in saturated waste rock zone.	Medium	**Yes**	Effectiveness largely unknown to site-specific waste rock (need treatability study). May be difficult to inject beneath, or infiltrate through, the existing cap over waste rock (another treatability study). Would likely be used in conjunction with other technologies.
	Amendments to groundwater	Install series of alkalinity injection wells in plume flowing through waste rock.	Potentially effective when combined with other technologies.	Implementable	High	**Yes**	May be used in conjunction with groundwater slurry wall and lake neutralization. Would likely require installation of new wells in affected flow paths.
Excavation	**Partial excavation of capped waste rock**	Pull back existing soil cap in selected areas and excavate waste rock using conventional earthmoving equipment. Amend remaining material and backfill.	Partially effective – removes source of acid-generating material.	Implementable	Low	**Yes**	Only removes a small portion of acid generating material but can readily be combined with other technologies.
Disposal	**On-site disposal**	Waste rock would be disposed of and managed (capped) within the former mine site.	Effective	Easy to implement	Low	**Yes**	There is sufficient space to place the expected quantities of material in an area not subject to groundwater infiltration.
	Off-site disposal	Disposal of material at a permitted landfill.	Effective	Implementable	High	No	Acid generating material would likely fail leach test requirements. High costs of transport and management.
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Table 1. Screening of Remedial Technologies for OU1 (continued page 3 of 3)

General Response Action	Remediation Technology and Process Option	Description of Process Option	Effectiveness	Implementability	Cost	Retained	Screening Comments
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	Aerobic wetland pond	A "polishing" passive treatment pond to remove dissolved sulfide, add oxygen and promote iron precipitation.	Effective if combined with other passive technologies to treat discharges.	Implementable	Medium	**Yes**	Aeration step required after treatment to remove dissolved sulfide and BOD and add oxygen prior to discharge to surface water.
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